Impact of Sea Surface Temperature Errors on Evaporative Duct Height

LCDR MARC C. ECKARDT, USN

Graduate Student, Department of Meteorology, Naval Postgraduate School, Monterey, California

ABSTRACT

The uncertainties of sea surface temperatures were used to determine differences in evaporative duct heights based on bulk calculations. Four different methods to measure sea surface temperature were taken and compared against one of the methods to determine the random error observed for the remaining three conditions, the random errors in the measurement of sea surface temperatures had different effects. For unstable conditions the errors had little impact on the duct height but for near neutral and stable cases, the error significantly altered the calculated value of the evaporative duct.

1. Introduction

The bulk calculation of the evaporative duct height requires at a minimum wind speed, air temperature, relative humidity and sea surface temperature (sst). Because the atmospheric evaporative duct is affected by evaporation at the very top (skin) of the sea surface, the ability to accurately measure the sst is difficult. To measure just a skin temperature is complicated and may require more advanced sensors like infrared guns; in contrast, measurements taken by more common and less expensive devices like in-line thermistor are measuring either intake temperatures below the sea surface or a representative temperature from the top of the mixed layer. Furthermore, each different method has its own degree of accuracy and can be prone to different error mechanisms. The question of exactly what is being measured vice what needs to be measured is one for theoretical discussion, but the question of how accurately does the sea surface need to be measured can be investigated.

Motivation for this project comes from several current Navy topics. Lockheed Martin is pushing to add a Tactical Environmental Processor (TEP) on all AEGIS ships that automatically gathers meteorological data and through the use of SPAWARs' Refractivity from Clutter model (RFC), calculates duct heights. The inputs for sea surface temperature come from either the seawater injection measurements, taken meters below the surface, or an installed infrared (IR) system that measures skin temperatures. Other projects, such as SMOOS, use float-sondes that measure the sea surface temperature in the top one-centimeter. All of these methods are currently deployed in the fleet and all have different error mechanisms, levels of accuracy and human intervention.

For this experiment, the impact of these sst errors are used to calculate the evaporative duct height differences in order to help answer the questions of how accurately can the sea surface be measured and what impact that accuracy (or lack thereof) has on other derived parameters. The hypothesis is that for some conditions, specifically unstable ones, the accuracy of the sst does not significantly impact the bulk calculation of the evaporative duct; however, for conditions near neutral or stable, the error in sst can cause large errors in the duct height.

2. Data sources

Three different data sets were used to investigate this issue and are listed in table (1). In order to compare and combine these data sets, each time was converted to decimal Julian-day and matched to a two-minute sample rate (with the exception of the manual observations taken at the top of every hour). Data taken from a previous voyage was incomplete and data taken during the turnover of student crews was unreliable. The combined dataset covers nine days and contains over 6000 data points.

Dataset	Parameter	Notes
Main Unit	Injection temp	Data output every 52 seconds
	Boom SST	
	Air temp	
	Relative Humidity	
Bow Unit	IR SST	Data sampled every 5 seconds, output every 2 minutes
	Wind speed	
Ship Log	IR SST (measured)	Data manually taken every hour
	IR Sky temp	

Table 1: Datasets and parameters used for experiment

a. Method One - Ships Injection Temperature

The ships seawater injection temperature provided the most stable and complete dataset and was therefore used as the baseline temperature for variation calculations. The depth of the intake can affect this method of measurement as well as where in the system the measurement is taken (before or after any pumps). In other words, the accuracy of this method can be affected by how well the surface layer is mixed and by any heat mechanically added to the system. The assumption is made that any heat added by the ship itself is insignificant and based on synoptic conditions, for the period of this dataset, the ocean surface layer was well mixed and the temperature of the intake representative of the sea surface temperature.

b. Method Two – Boom Temperature

A boom lowered into the water and dragged behind the ship provided another stable dataset. Unlike the intake method, the boom method measured the very top of the surface layer with a similar device as the intake (basic thermistor). Though the boom did not measure the “skin” temperature, it is assumed that the surface layer is well mixed. Subsequently, this dataset is also taken to be representative of the true sea surface temperature but stopped recording shortly after the second underway.

c. Method Three – Ship Mounted Infrared Temperature

An IR sensor mounted on the bow provided a very sporadic and questionable dataset. Theoretically, the IR gun measures the skin temperature of the sea surface and based on an understanding of air-sea interaction, should be cooler than the temperature a few centimeters down due to the latent heat loss of evaporation. However, this temperature set is significantly warmer that the others and at times is as much as four degrees higher. The variability of the data is also higher, which leads to the questions of whether this dataset is not representative of the actual sst or whether the fluctuations are real and there is that much random variability in the measurement. Other error mechanisms such as cleaning the IR sensor, the effect of the ships motion and the contamination from atmospheric infrared radiation are not addressed.

d. Method Four – Handheld Infrared Temperature

The final dataset was taken manually using a handheld IR gun. Though similar to the method described above, a second reading of the sky temperature was taken concurrently which allowed the contamination from atmospheric infrared radiation to be removed. A calculated sst was achieved using equation (1):

$$T_{sea} = \left[\frac{T^4_{meas} - (1-\varepsilon)T^4_{sky}}{\varepsilon} \right]^{1/4} \qquad (1)$$

where epsilon (ε), the emissivity of seawater is 0.98. Other error mechanisms such as cleaning the IR sensor, the competency of the user(s) and the accuracy of the sky temperature are not addressed.

3. Sea Surface Temperature Errors

Figure (1) is a simple time series of the four datasets described above. Dataset one (injection temperature) was chosen as the baseline temperature and subtracted out of the other datasets to produce figure (2), a difference plot of sst from injection temperatures. The mean temperature and standard deviation was then calculated for each temperature difference dataset, including the raw handheld IR gun, and plotted in figure (3). As expected from observation of figure 1, the ship IR sensor was the erratic; what was not anticipated was such a close correlation between the boom temperature and the injection temperature. Surprisingly, the standard deviation of this difference was 0.01 with the boom temperature always slightly higher than the injection temperature. Hypothetically assuming that the injection temperature was the exact sst, careful calibration of the other sensors could remove the mean difference; however the random error for each method cannot be controlled. Figure (4) is an attempt to correlate the ship IR sst differences to another environmental parameter but though the air temperature appears to have a similar pattern, a scatter plots clearly shows no such dependency exists.

Of interest, the validation of radiative theory was shown in the handheld IR sensor through the calculation of sst using equation (1). Instead of using the measured value of the sea surface, the contamination from the atmosphere was removed and made a slight improvement in the overall dataset (decrease in the standard deviation). Figure (5) is the difference of measured IR sst and sky temperatures and graphically shows that for the majority of the cruise it was foggy. However, short clear periods did exist and it was during those times when the temperature adjustment made the biggest difference (up to five percent). Were conditions different, the adjustment for the atmosphere would be more significant than found in this dataset.

4. Evaporation Duct Height

The calculation of the evaporative duct height was accomplished using the bulk method, specifically a model written by Paul Frederickson at the NPS. For comparative purposes, an initial calculation was made with raw data differences on the evaporative duct height with limits of 100 meters. Of note, the term “evaporative duct height” is a bit misleading, what is actually being calculated is the height at which the slope of the refractivity (M) profile is zero. Figure (6) corresponds to figure (1) and shows that for most of the cruise, the differences in sst had little impact on the calculation of the duct height; however, there are also times when the variations in sst make large differences in the duct height.

To investigate the effect of the random error of sst on the calculation of the duct height, the dataset of the injection temperature was altered with a nominal standard deviation of 0.5 degrees. This value was chosen for two reasons: one, the average of the IR sensor standard deviations was about 0.5 and two, for fleet purposes, being able to measure the actual sst within ½ a degree is a minimum requirement. Like figure (6), figure (7) shows that for a majority of the cruise a difference of 0.5 degrees makes only a few meter difference in the calculation of the duct height. Clearly though, there are times when ½ of a degree makes a large difference. To understand what mechanism is at work here, the difference in duct heights caused by one standard deviation in sst (plus 0.5º and minus 0.5º) were plotted against wind speed and relative humidity [figure (8)]. An obvious correlation exists between the duct height difference and the air temperature, specifically the air-sea temperature difference. Figure (9) shows that for this cruise, conditions were close enough to neutral that when the sst difference is applied, it can cause the air-sea temperature difference to switch from unstable to neutral, neutral to stable or unstable to stable. This change in stability conditions with one standard deviation significantly impacts the duct height.

Another case using the actual ship IR sst and observed standard deviation was run for completeness. Since the IR sst were on average 1.7 degrees higher than the injection sst, for these atmospheric conditions the results were less dramatic because the stability was more unstable [figure (10)]. There were still several instances where the random error of the ship IR sensor made a significant difference in the duct height calculation, specifically under stable conditions. Again, correlations between the wind speed and relative humidity were ruled out [figure (11)] and the measured stability of the air-sea interface the key factor in determining the duct height errors [figure (12)].

5. Conclusions

Concrete conclusions can be made from this study but it is important to clarify the scope of these conclusions. The numbers of measurement methods were limited and though over 6000 data points were available, the conditions under which the data was taken were similar. A more exhaustive study using more sensors under different atmospheric conditions would solidify these results. Additionally, the assumptions in the study limit the comparisons between the different measurement methods; specifically, the handheld IR sensor was corrected for atmospheric contamination but the ship IR sensor was not. No records were kept that indicated the calibration of any sensors or whether or not the IR sensors were routinely and adequately cleaned during operation. Additionally, this study does not address other characteristics of the evaporative duct. For stable conditions, the evaporation duct is normally not as defined as in unstable conditions. Therefore with a flatter refractivity (M) profile, subtle changes in input parameters can cause large differences in the duct axis height but no real difference in the overall profile of the entire evaporative duct.

What can be concluded is that the calibration of sst sensors is important. Routinely on naval vessels, the sea water injection temperature over 5 meters deep provides the data source for sst into other tactical decision aids such as AREPS, RFC or TEP. Measuring for sky IR contamination is also important and can cause up to as much as a five percent correction factor. As shown in this study [figure (13)], for similar atmospheric conditions (~95% relative humidity and > 8 m/s wind), one half of a degree variation can make significant changes in the duct height calculation when conditions are stable.

List of Acronyms

AREPS	Advanced Refractive Effects Prediction System
NPS	Naval Postgraduate School, Monterey, CA
RFC	Refractivity from Clutter
SMOOS	Shipboard Meteorological and Oceanographic Observation System